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A new technique for spectroscopy of atomic hydrogen has been developed, opening the way to a thousand-fold increase in spectroscopic resolution of hydrogen-or any neutral atomic species, and perhaps making possible a new type of UV optical atomic clock.

Two-photon Doppler-free spectroscopy of atoms confined in a magnetic trap has been carried out to observe the 1S to 2S two-photon (243nm) transition to a metastable state with an extremely long lifetime, 1/8 sec. The trap is highly non-perturbative, permitting observation times limited ultimately by the natural lifetime, yielding a natural linewidth of about 1 Hz. Initially a resolution of about three kHZ was achieved, higher than the best then achieved by other techniques and apparently limited only by laser jitter. Signal rates as high as 3000 counts per second were observed. The collection efficiency in the initial version of the apparatus is less than 10^{-5}, and the actual signal rate is greater than 10^{8} counts per second, almost astronomically high compared to previous methods. A direct measurement of the life time of the metastable 2S atoms was made and found to be close to the theoretical lifetime of 0.12 sec. This is the first time the 2S lifetime has been measured.

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December 18, 1996

Dr. Ralph Kelley
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Dear Dr. Kelley,

The is the Final Report for AFOSR Grant F49620-93-1-0215.

Under this grant we have developed a new technique for spectroscopy of atomic hydrogen which opens the way to a thousand-fold increase in spectroscopic resolution of hydrogen—or indeed any neutral atomic species—and may make possible a new type of optical atomic clock operating in the UV region.

We have succeeded in carrying out two-photon Doppler-free spectroscopy of atoms that are confined in a magnetic trap. The transition we observe, the $1S \rightarrow 2S$ two-photon (243nm) transition, is to a metastable state with an extremely long lifetime, 1/8 sec. The trap is highly non-perturbative, permitting observation times limited ultimately by the natural lifetime, yielding a natural linewidth of about 1 Hz. In our initial experiments we achieved a resolution of about three kHZ, higher than the best then achieved by other techniques and apparently limited only by laser jitter, which we are now trying to improve. We have observed signal rates as high as 3000 counts per second. The collection efficiency in the initial version of our apparatus is less than 10^{-5}, and so the actual signal rate is greater than 10^{8} counts per second, which compared to previous methods, is almost astronomically high. In addition, we have directly measured the life time of the metastable 2S atoms, and have observed it to be close to the theoretical lifetime of 0.12 sec. This is the first time the 2S lifetime has been measured.

The performance of our system gives promise that a new type of optical clock, based on the $1S \rightarrow 2S$ two-photon transition in hydrogen, may be feasible. We have started an analysis of this system with a view to creating such a clock. In addition, the spectroscopic techniques developed in this work provide a powerful tool for studying Bose-Einstein condensation in hydrogen, and the possible creation of a coherent atomic beam of hydrogen- a hydrogen atom laser.

PUBLICATIONS AND THESES

Two-photon spectroscopy of trapped atomic hydrogen, Claudio L. Cesar, Dale G. Fried, Thomas C. Killian, Adam D. Polcyn, Jon C. Sandberg, Ite A. Yu, Thomas J. Greytak, Daniel Kleppner, and John Doyle, Phys. Rev. Lett. **77**, 255 (1996)

Two-Photon Spectroscopy of Trapped Atomic Hydrogen, C. L. Cesar, D. G. Fried, T. C. Killian, A. D. Polcyn, J. C. Sandberg, J. M. Doyle, I. A. Yu, T. J. Greytak and D. Kleppner, Proceedings of the Fifth Symposium on Frequency Standards and Metrology, J. C. Bergquist, ed. (World Scientific, Singapore) 1996, p 365.

Doppler-Free Spectroscopy of Trapped Atomic Hydrogen, T.C. Killian, D.G. Fried, C.L. Cesar, A.D. Polcyn, T.J. Greytak and Daniel Kleppner, Proceedings of the Fifteenth International Conference of Atomic Physics, to be published

(In preparation) Two-photon Doppler-Free Spectroscopy of Trapped Atoms, Claudio L. Cesar and Daniel Kleppner

THESES

Claudio L. Cesar, Ph.D. thesis Two-Photon Spectroscopy of Trapped Atomic Hydrogen, M.I.T., December 1995

Sincerely,

Dan Kleppner

Daniel Kleppner
Lester Wolfe Professor of Physics